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Comments on the Draft Updated Scientific Analysis

to Support New Storage and Conveyance

The Updated Scientific Analysis to Support New Storage Conveyance is simply a collection of articles, with no clear analysis, synthesis, or narrative conclusions. California Water Research has been providing relevant research articles on climate change to the Delta Stewardship Council since 2012, with appropriate analysis and synthesis. The Delta Independent Science Board has also previously made very clear recommendations with respect to consideration of climate change in the Bay Delta Conservation Plan / WaterFix project, which are still relevant, and which were not followed. California Water Research hereby submits this supplemental updated scientific analysis for consideration in analysis of the proposed Delta Plan amendments.

There have been significant advances in the scientific understanding of climate change since the initial modelling for the BDCP / WaterFix conveyance projects that took place from 2009-2012. These advances have been driven by data collected during recent, dramatic phenomena, including the accelerated melting of ice sheets in the west Antarctic and Greenland and severe, prolonged droughts in the Southwestern United States, Midwestern United States, and California. Recent temperature deviations also make the lower sensitivity Global Climate Models, which predict less than 3 degrees of warming with a doubling of C02, appear increasingly unlikely.[1]

Recent observations and research point towards a much hotter and potentially drier future, with the potential for much greater increases in sea level rise than were previously predicted. The most recent scientific literature and climate change modeling points toward major risks to water supply and water quality in the Delta. The projects incorporated into the Delta Plan need to address these risks.

These comments address the current best available science in the following areas, which are critical to future water supply reliability.

1. Sea Level Rise
    a. Standards Used in the Waterfix EIR/EIS
    b. Updated Ocean Protection Council Standards
    c. US Army Corps of Engineers Guidance
    d. Past Guidance by the Delta Independent Science Board
    e. Other Relevant Federal Guidelines
    f. Estimating Contributions to Water Supply Reliability
    g. Simulated Operations at High Sea Level Rise

2. Droughts

3. Shifts in Hydrology Due to Climate Change
    a. Regional Bias in CMIP Climate Change Models
    b. BDCP /WaterFix Approach to Uncertainty in Climate Change Models

4. Change in Frequency of Extreme Events

As explained in the comments, there are significant deficiencies in the use of the best available science in the analysis BDCP/WaterFix CEQA/NEPA documents in all of these areas. Failure to adequately consider risks significantly compromises the project's ability to increase water supply reliability.

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[1]S.C. Sherwood, S. Bony, and J. Dufresne, Spread in model climate sensitivity traced to atmospheric convective mixing, 505 Nature pp. 37-42, 2014. Available at http://dx.doi.org/10.1038/nature12829.

Sincerely,

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Deirdre Des Jardins
California Water Research

Cc: Delta Independent Science Board members

Climate Change Considerations for Water Supply Reliability

1. Sea Level Rise

The largest new conveyance being considered is the WaterFix, three new 3,000 cfs diversions in the North Delta for the State Water Project and Central Valley Project. The WaterFix is also the new conveyance which will be most impacted by sea level rise. The Delta Reform Act of 2009 required a comprehensive analysis of sea level rise up to 55 inches for inclusion in the Delta Plan. As the analysis below shows, 55 inches is now given a 5% chance of exceedance by 2100.

a.) Standards Used in the Waterfix EIR/EIS

Section 9.2.2.6 of Chapter 9 of the WaterFix Final EIR/EIS indicates that the following guidance for sea level rise is being used for the design of the WaterFix facilities:

> The State of California Sea-Level Rise Task Force of the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), Sea-Level Rise Interim Guidance Document, 2010. This document provides guidance for incorporating sea level rise projections into planning and decision making for projects in California. Using Year 2000 as a baseline, the sea level rise projections in California range between 10 and 17 inches by year 2050 and between 18 and 29 inches by year 2070.
>
> - Underestimating sea level rise in the project design will result in harmful realized impacts such as flooding. Harmful impacts are more likely to occur if the project design is based upon a low projection of sea level rise and less likely if higher estimates of sea level rise are used. In situations with high consequences (high impacts and/or low adaptive capacity), using a low sea level rise value involves a higher degree of risk. (Examples of harmful impacts that might result from underestimating sea level rise include damage to infrastructure, contamination of water supplies due to saltwater intrusion, and inundation of marsh restoration projects located too low relative to the tides).
>
> - As of the date of the guidance document, the State Coastal Conservancy (SCC) and the State Lands Commission (SLC) have adopted, and the Delta Vision Blue Ribbon Task Force Independent Science Board has recommended, the use of 55 inches (140 cm) of sea level rise for 2100. The SCC and the SLC also adopted a policy of using 16 inches (41 cm) as the estimate of sea level rise for 2050. Agencies may select other values depending on their particular guiding policies and considerations related to risk, ability to incorporate phased adaptation into design and other factors.

b.) Updated Ocean Protection Council Standards

The Ocean Protection Council Science Advisory Team (OPC-SAT) Working Group has been updating the 2010 interim sea level rise guidance by the State of California Sea-Level Rise Task Force of the Coastal and Ocean Working Group, and just published an updated report.[2]

Under the highest Greenhouse Gas concentration pathway (RCP 8.5) the OPC-SAT Working Group estimated a 5% chance that sea level rise at the Golden Gate will be greater than 53 inches (4.4 feet) by 2100, and a 0.5% chance that sea level rise will exceed 6.9 feet by 2100.

For new infrastructure, 95% exceedance should be a minimum design criteria for the expected lifetime of the project, and 99% or higher would be preferable. The table on page 28 of the OPC-SAT Working Group report (reproduced below) shows the OPC-SAT Working Group estimates of probabilities of sea level rise at the Golden Gate. The table includes estimates for medium and low Greenhouse Gas Emissions scenarios (RCP 4.5 and RCP 2.6.) The extreme value of 10 feet by 2100, identified as H++ in the table, was estimated by Sweet et. al. for NOAA and will be discussed in more detail below.

These higher sea level rise estimates should not be a surprise. In 2007, the Delta Independent Science Board recommended that the Bay Delta Conservation Plan use a median estimate of one meter (55 inches) of sea level rise for 2100, and use empirical estimates by the method of Rahmstorf. However, the ISB cautioned in their 2007 guidance that ice sheet melting could result in as much as 2 meters of sea level rise by 2100.[3]

As documented in the 2013 BDCP Draft EIR/ Draft EIS, the Department of Water Resources and the U.S. Bureau of Reclamation knew by 2012 that the sea level rise estimates in the BDCP simulations were out of date, and that sea level rise could reach 1.67 meters by 2100:

> The "[b]est available information suggests a range of potential SLR from 17 to 66 inches (42 to 167 centimeters) by 2100 (National Research Council 2012).
>
> (BDCP DEIR/DEIS, Chapter 29, p. 13:24-25).

However, the lead agencies decided not to update the 2007 sea level rise assumptions.

According to the BDCP DEIR/DEIS,

> The projections from the NRC study were not used directly in the BDCP analysis for two reasons.

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[2] Griggs, G, Árvai, J, Cayan, D, DeConto, R, Fox, J, Fricker, HA, Kopp, RE, Tebaldi, C, Whiteman, EA (California Ocean Protection Council Science Advisory Team Working Group). *Rising Seas in California: An Update on Sea-Level Rise Science*. California Ocean Science Trust. 2017. Available at http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf

[3] Healy, Mike. Letter to Jeffrey Mount, Chair, Delta Independent Science Board. 2007. Available at http://calwater.ca.gov/science/pdf/isb/meeting_082807/ISB_response_to_ls_sea_level_090707.pdf

> 1) the study was published in June 2012, well after the modeling analysis for BDCP had been designed and performed, and
> 2) the projection years are not directly aligned with the 2025 and 2060 analysis periods used for BDCP.
>
> (Chapter 29, p. 13:27-29)

However, as discussed below, the Army Corps of Engineers sea level rise guidance has provided equations for calculating low, intermediate, and high sea level rise estimates from the National Research Council guidelines since 2011.

c.) US Army Corps of Engineers Guidance

The WaterFix Final Draft EIR/EIS cites the 2011 Army Corps of Engineers' Circular EC 1165-2-212, Sea-Level Change Considerations for Civil Works Programs. [4] However, an examination of the USACE 2011 guidance for incorporating sea level change in civil works programs shows that the use of a single intermediate value for sea level rise is inconsistent with that guidance.

In the circular, the Army Corps recommends using "low", "intermediate", and "high" rates of sea level rise for the project lifetime, calculated from curves modified from the National Research Council's sea level rise guidance. The Army Corps of Engineers' Regulation, *Incorporating Sea Level Change in Civil Works Programs*, released in December 2013, superseded EC 1165-2-212.[5] The Regulation states:

> (3) The low, intermediate, and high scenarios at NOAA tide gauges can be obtained through the USACE on-line sea level calculator at http://www.corpsclimate.us/ccaceslcurves.cfm

The closest NOAA tide gauge to the Delta is at Port Chicago. The USACE low, intermediate, and high scenarios at the NOAA tide gauge at Port Chicago are shown in the graph on the next page. The curves were calculated through 2135, which is the end of the estimated 100 year lifetime of the project, if it is completed by 2135. The USACE intermediate and high rates of sea level rise are somewhat lower than those estimated by NOAA, but similar.

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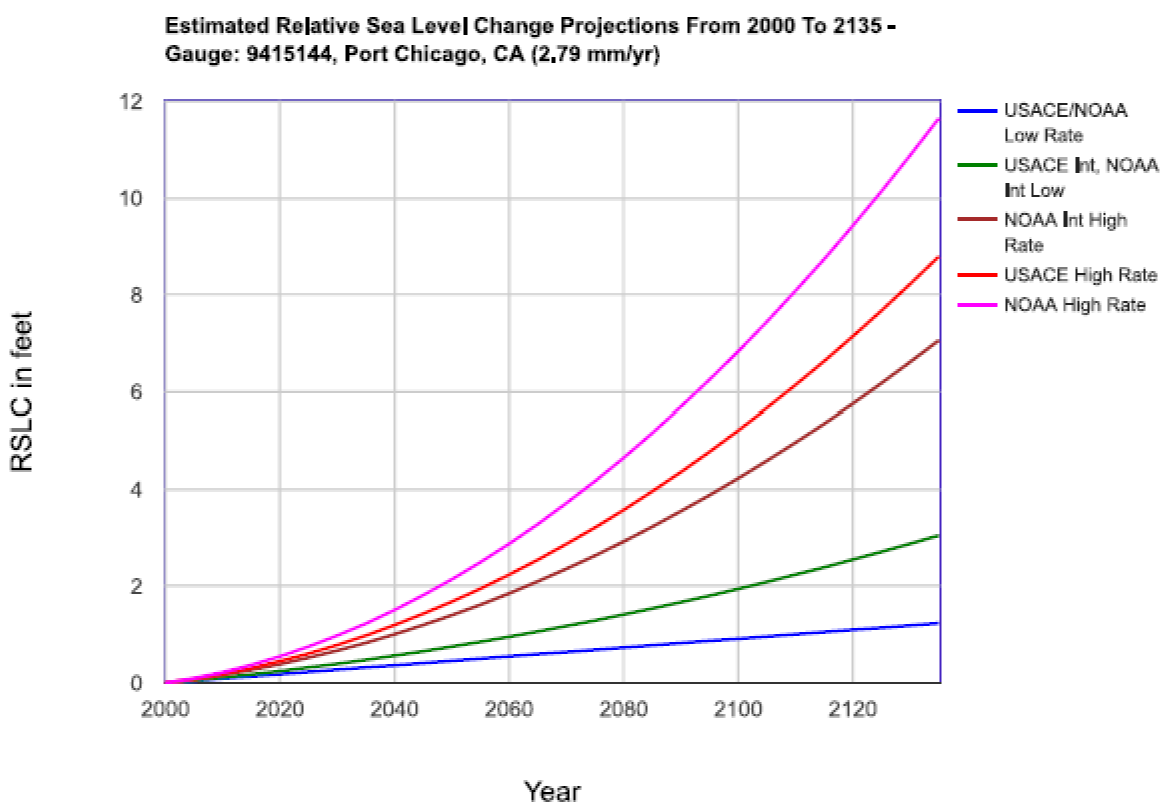
[4] U.S. Army Corps of Engineers' Circular EC 1165-2-212, Sea-Level Change Considerations for Civil Works Programs, 2011. Available at http://web.law.columbia.edu/sites/default/files/microsites/climate-change/usace_circular_no_2265-2-212.pdf This was preceded by the U.S. Army Corps of Engineers' Circular EC EC 1165-2-211, Sea-Level Change Considerations for Civil Works Programs, 2009. Available at http://www.dbw.ca.gov/csmw/pdf/EC_Sea_Level_Change.pdf

[5] US. Army Corps of Engineers' Regulation ER 1100-2-8162, Incorporating Sea Level Change in Civil Works Programs, released in December 2013. Available at http://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1100-2-8162.pdf

With respect to using the “low”, “intermediate”, and “high” sea level rise estimates, the 2011 Army Corps sea level rise guidance states:

> b. Planning studies and engineering designs over the project life cycle, for both existing and proposed projects consider alternatives that are formulated and evaluated for the entire range of possible future rates of sea-level change (SLC), represented here by three scenarios of “low,” “intermediate,” and “high” sea-level change. These alternatives will include structural and nonstructural solutions, or a combination of both. Evaluate alternatives using “low,” “intermediate,” and “high” rates of future SLC for both “with” and “without” project conditions. (p.2)



The 2011 Army Corps sea level rise guidance also states:

> c. Determine how sensitive alternative plans and designs are to these rates of future local mean SLC, how this sensitivity affects calculated risk, and what design or operations and maintenance measures should be implemented to minimize adverse consequences while maximizing beneficial effects. Following the approach described in 6b above, alternative plans and designs are formulated and evaluated for three SLC possible futures. Alternatives are then compared to each other and an alternative is selected for recommendation. The approach to formulation, comparison and selection should be

tailored to each situation. The performance should be evaluated in terms of human health and safety, economic costs and benefits, environmental impacts, and other social effects. There are multiple ways to proceed at the comparison and selection steps. Possible approaches include:

> (1) Working within a single scenario and identifying the preferred alternative under that scenario. That alternative's performance would then be evaluated under the other scenarios to determine its overall potential performance. This approach may be most appropriate when local conditions and plan performance are not highly sensitive to the rate of SLC. (p. 2)

The same guidance continued in the 2013 Regulations.

While the Department of Water Resources has worked within a single, intermediate sea-level rise scenario, and identified alternatives under that scenario, the alternative's performance has not been evaluated under other sea level rise scenarios to determine its potential performance. Evaluating the performance of the project and risk of adverse consequences under other sea level rise scenarios was exactly is recommended not only by the Army Corps of Engineers guidance, but also by the Delta Independent Science Board.

d.) Past Guidance by the Delta Independent Science Board

In a 2014 review of the BDCP Draft Environmental Impact Report/Draft Environmental Impact Statement ("DEIR/DEIS"), the Delta Independent Science Board ("ISB") stated,

> *The potential effects of climate change and sea-level rise are underestimated*. . . . The potential direct effects of climate change and sea-level rise on the effectiveness of actions, including operations involving new water conveyance facilities, are not adequately considered. . . .
>
> In their response to our preliminary draft review, the Department of Water Resources noted that "the scope of an EIR/EIS is to consider the effects of the project on the environment, and not the environment on the project". If the effects of major environmental disruptions such as climate change, sea-level rise, levee breaches, floods, and the like are not considered, however, one must assume that the actions will have the stated outcomes. We believe this is dangerously unrealistic. CEQA requires impacts to be assessed "in order to provide decision makers enough information to make a reasoned choice about the project and its alternatives".[6]

[6] Letter from Delta Independent Science Board to Randy Fiorini, Chair, Delta Stewardship Council, May 15, 2014. (Appendix, p. 6, footnotes omitted.) Available at http://deltacouncil.ca.gov/sites/default/files/documents/files/Attachment-1-Final-BDCP-comments.pdf

Feet above 1991-2009 mean	MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE
Year / Percentile	50% probability SLR meets or exceeds…	67% probability SLR is between…	5% probability SLR meets or exceeds…	0.5% probability SLR meets or exceeds…
2030	0.4	0.3 — 0.5	0.6	0.8
2050	0.9	0.6 — 1.1	1.4	1.9
2100 (RCP 2.6)	1.6	1.0 — 2.4	3.2	5.7
2100 (RCP 4.5)	1.9	1.2 — 2.7	3.5	5.9
2100 (RCP 8.5)	2.5	1.6 — 3.4	4.4	6.9
2100 (H++)	10			
2150 (RCP 2.6)	2.4	1.3 — 3.8	5.5	11.0
2150 (RCP 4.5)	3.0	1.7 — 4.6	6.4	11.7
2150 (RCP 8.5)	4.1	2.8 — 5.8	7.7	13.0
2150 (H++)	22			

1Sea level rise at the Golden Gate *Source: OPC-SAT, Rising Seas in California, April 2017*

e.) Other Relevant Federal Guidelines

The sea level rise assumptions used in the 2013 Draft EIR/EIS were also inconsistent with federal agency guidelines. For the National Climate Assessment in 2012, Sweet et. al. at the Climate Change Program Office of the National Oceanic and Atmospheric Association (NOAA) derived a high estimate of 2 meters by 2100.[7] The U.S. Army Corps of Engineers estimated that sea level rise could reach 1.6 meters by 2100. The values have been available in the U.S. Army Corps of Engineers' online sea level rise calculator since 2014. Values from the U.S. Army Corps calculator for the Golden Gate are shown in the graph on the next page.[8]

As explained in 2015 comments by California Water Research on the WaterFix Revised Draft EIR/EIS, the best available science shows that sea level rise is accelerating:

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[7] Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler and CZ. NOAA Technical Report NOS CO-OPS 083, Global and Regional Sea Level Rise Scenarios for the United States. 2017. Available at https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf.

[8] U.S. Army Corps of Engineers, Sea Level Change Calculator. 2015. Available at http://www.corpsclimate.us/ccaceslcurves.cfm

Estimates of sea level rise were an area of significant scientific uncertainty when DWR first did sensitivity studies for BDCP. At that time, there was significant uncertainty about potential contributions from melting of the polar ice sheets. But recent observations have shown that the rate of mass loss in the ice sheets in the west Antarctica and Greenland has been accelerating significantly. In December 2014, the American Geophysical Union accepted a paper by Tyler Sutterly and colleagues at UC Irvine and NASA JPL which found that the melt rate of glaciers in the Amundsen Sea Embayment in West Antarctica had tripled in the last decade.[9] The analysis was comprehensive and authoritative, evaluating and reconciling data from 4 different measurement techniques over 21 years.

For the National Climate Assessment in 2012, the Climate Change Program Office of the National Oceanic and Atmospheric Association (NOAA) used empirical estimates of the rate of acceleration of ice sheet melting to derive potential values of sea level rise as high as 2 meters (6.6 feet or 79 inches) by 2100.[10] NOAA recommended that the highest levels be used where there is little tolerance for risk, such as in a new infrastructure process. Unfortunately, the highest estimate of sea level rise estimated by DWR's modelling for the Draft EIR/EIS was about 94 cm (3.1 feet or 37 inches) by 2100, about 50% of NOAA's 2012 empirical estimate. DWR's 95% confidence projection of 3.9 feet or 46 inches by 2100 was about 60% of NOAA's empirical estimate. These values were used to derive the estimate of 15 cm (0.5 ft or 6 inches) of sea level rise by 2025, and 45 cm (1.5 ft or 18 inches) by 2060 used in the WaterFix Revised DEIR/Supplemental DEIS.

The current "best available science" projections show risks of sea level rise of up to 2 meters by 2100. The guidance by state and federal agencies is to consider risks of higher levels of sea level rise. The 18 inch estimate used in design and simulated creates potentially huge risk for a $17 billion project that will provide water supply for 25 million people.

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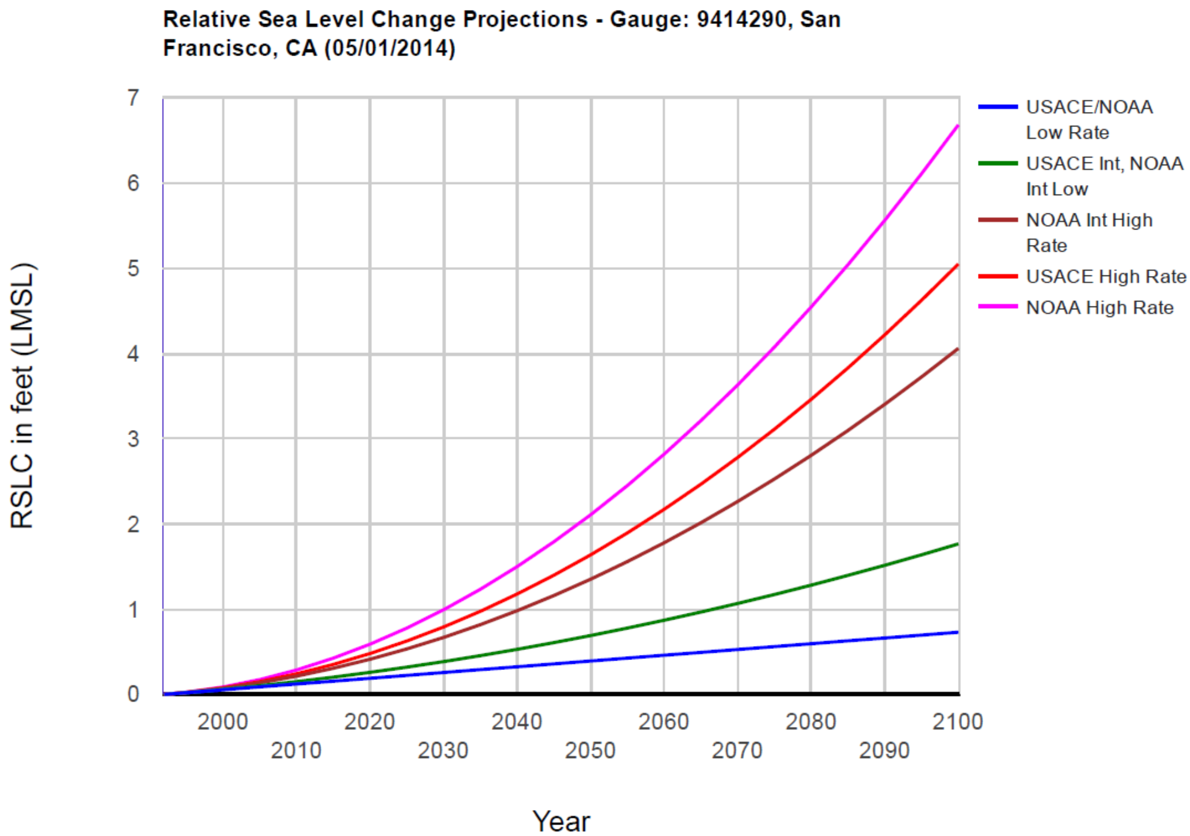
[9] Sutterley, T. C., I. Velicogna, E. Rignot, J. Mouginot, T. Flament, M. R. van den Broeke, J. M. van Wessem, and C. H. Reijmer (2014), Mass loss of the Amundsen Sea Embayment of West Antarctica from four independent techniques, Geophys. Res. Lett., 41, 8421–8428, doi:10.1002/2014GL061940. Available at http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/PCFFA&IGFR/PCFFA_63_Sutt.pdf.

[10] Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. Available at http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/PCFFA&IGFR/PCFFA_10_NOAA.pdf



f.) Estimating Contributions to Water Supply Reliability

To evaluate the contribution of the conveyance to reliability of water supply, the Delta Stewardship Council should consider the exceedance estimates in the table on p. 31 of the Ocean Protection Council's Science Advisory Team's (OPC-SAT's) risk report. The most relevant estimates for reliability are the estimates for the highest greenhouse gas concentration pathway, RCP 8.5. According to the table, under RCP 8.5, there is a 28% chance that sea level rise at the Golden Gate will exceed 3 feet by 2100, and an 8% chance it will exceed 4 feet. (Reproduced on the following page.)

Table 4. Probability that sea-level rise at San Francisco, Golden Gate, will meet or exceed a particular height (feet) in a given year under: (a) RCP 8.5, and (b) RCP 2.6.

Estimates are based on Kopp et al., 2014. All heights are with respect to a 1991-2009 baseline; values refer to a 19-year average centered on the specified year. Grey shaded areas have less than a 0.1% probability of occurrence.

(a) RCP 8.5

	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2020										
2030	0.1%									
2040	3.3%									
2050	31%	0.4%								
2060	65%	3%	0.2%	0.1%						
2070	84%	13%	1.2%	0.2%	0.1%					
2080	93%	34%	5%	0.9%	0.3%	0.1%	0.1%			
2090	96%	55%	14%	3%	0.9%	0.3%	0.2%	0.1%	0.1%	
2100	96%	70%	28%	8%	3%	1%	0.5%	0.3%	0.2%	0.1%
2150	100%	96%	79%	52%	28%	15%	8%	4%	3%	2%
2200	100%	97%	91%	80%	65%	50%	36%	25%	18%	13%

21Sea level rise exceedances at the Golden Gate Source: OPC-SAT, Rising Seas in California, April 2017

g.) Simulated Operations at High Sea Level Rise

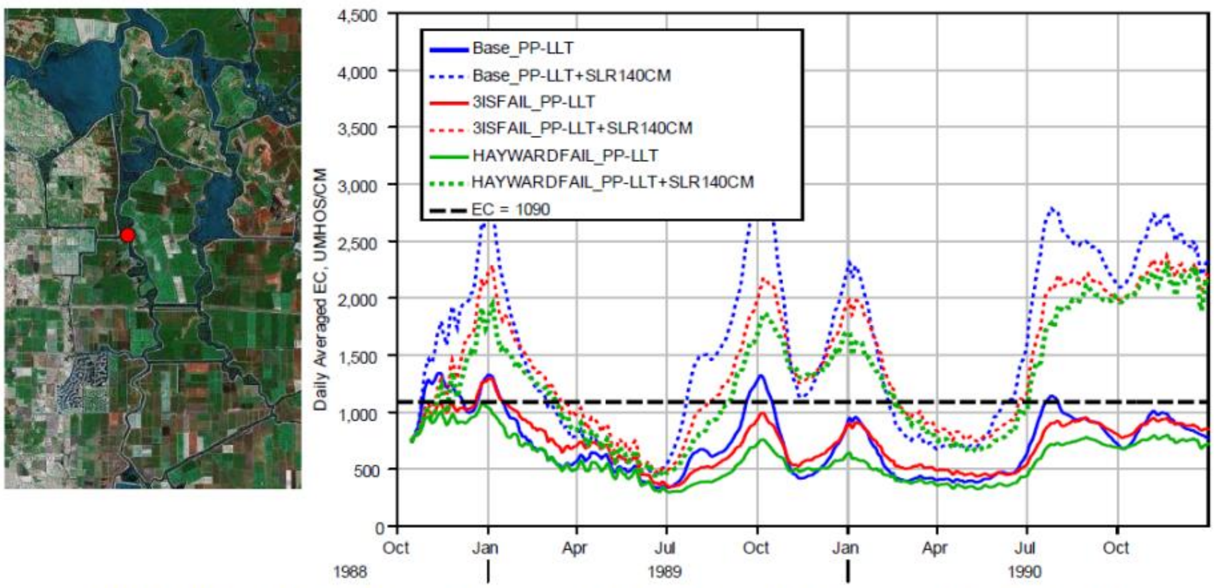
The WaterFix Final EIR/EIS notes that WaterFix operations could change under high se level rise, allowing uncontrolled salinity intrusion into the Delta:

> The location of the north Delta diversion facility is further inland making it less vulnerable to salinity intrusion. Even with substantial sea level rise and critically dry upstream conditions, salinity could be repelled from this location. By establishing an alternative diversionpoint for Delta exports, a great deal of Delta management flexibility is added. Currently, management of the Delta is constrained by requirements to maintain X2 at specific locations during certain times of the year to ensure water diversions have low salinity and to ensure that critical fish populations stay outside of the entrapment zone. Alternatives 1A–2C, 3, 4, and 5 would allow the Delta to be managed in a number of different ways, including maintaining salinity as it is currently managed or allowing salinity

to fluctuate more freely in the Delta as it did prior to the development of upstream reservoirs. (Chapter 29, p. 16.)

Below is an early simulation of the BDCP project operating at 15,000 cfs with long term levee failure (3 islands) and high sea level rise (1.4 meters or 55 inches.) Base_PP is 15,000 cfs at Late Long Term. Base_PP+SLR 140cm is with sea level rise of 1.4 meters (55 inches.) 3ISFAIL_PP-LLT is a 15,000 cfs conveyance with 3 Delta Island failures. HAYWARDFAIL_PP-LLT is a 15,000 cfs conveyance with 20 Delta Island failures. There is extreme salinity intrusion with 140cm of sea level rise, ironically less with Delta Island failures because they hold fresh water in the Delta.

Daily Averaged EC at ROLD024



•With 140 cm SLR, EC frequently exceeds 1090 umhos/cm, thus export adjustments are significant
•Without SLR, periods of export adjustment are brief for Base and 3 Island cases
•No export adjustments are made for the Hayward case with no SLR

There is a risk that these kinds of operations would be considered not just at the end of century with high sea level rise, but also during extended droughts. This creates significant risk for beneficial needs in the Sacramento-San Joaquin Delta. The following section considers the risk of droughts.

2. Droughts

In looking at contributions to water supply reliability, it is important to assess the risk of shifts in climate. The WaterFix project analysis (and likely also the analysis for the CCWD intake and North Bay Aqueduct intake) project shifts in hydrology onto a repeat of the 82 year historical record. There is a risk that this kind of projection misses possible shifts in climate, either due to climate change or due to natural variability. In 2010, the Department of Water Resources' published an analysis of modeling for climate change, and noted that[11]

> there is a lack of analysis of potential drought conditions that are more extreme than have been seen in our relatively short hydrologic record. There is significant evidence to suggest that California has historically been subject to very severe droughts and that climate change could result in droughts being more common, longer, or more severe. However, most current DWR approaches rely on an 82-year historical hydrologic record (1922–2003) on which GCM-generated future climate changed-hydrologic conditions are superposed. This record is likely too short to incorporate the possibility of a low frequency, but extreme, drought.

The Department of Water Resources did fund a study of tree ring cores by David Meko at the University of Arizona.[12] Meko's study estimated the Sacramento Four River Index from tree ring cores, back to 901 A.D. Graphs of Meko's reconstructed flows, along with the associated data set, are available at http://www.treeflow.info/content/sacramento-river-four-rivers-index-ca. The graphs show many extended periods of below average flows.[13] See also Cook et. al..[14]

In a presentation for the 2009 Extreme Precipitation Symposium, David Meko stated that

> six-year droughts of the 1930s and 1980s-90s are as severe as any encountered in the tree-ring record. For longer running means the tree-ring record contains examples of drought severity and duration without analog since the start of the 20th century. For

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[11] Abdul Khan and Andrew Schwarz, Climate Change Characterization and Analysis in California Water Resources Planning Studies, Final Report. DWR, p. xvi (Dec. 2010), *available at* http://www.water.ca.gov/climatechange/docs/DWR_CCCStudy_FinalReport_Dec23.pdf

[12] David M. Meko, Matthew D. Therrell, Christopher H. Baisan, and Malcolm K Hughes, *Sacramento River Flow Reconstructed To Ad. 869 From Tree Rings*, Journal Of The American Water Resources Association, VOL. 37, NO.4, August 2001. Available at http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/PCFFA&IGFR/PCFFA_74_Meko01.pdf

[13] Graphs and data from David Meko's reconstruction as presented at http://www.treeflow.info/content/sacramento-river-four-rivers-index-ca
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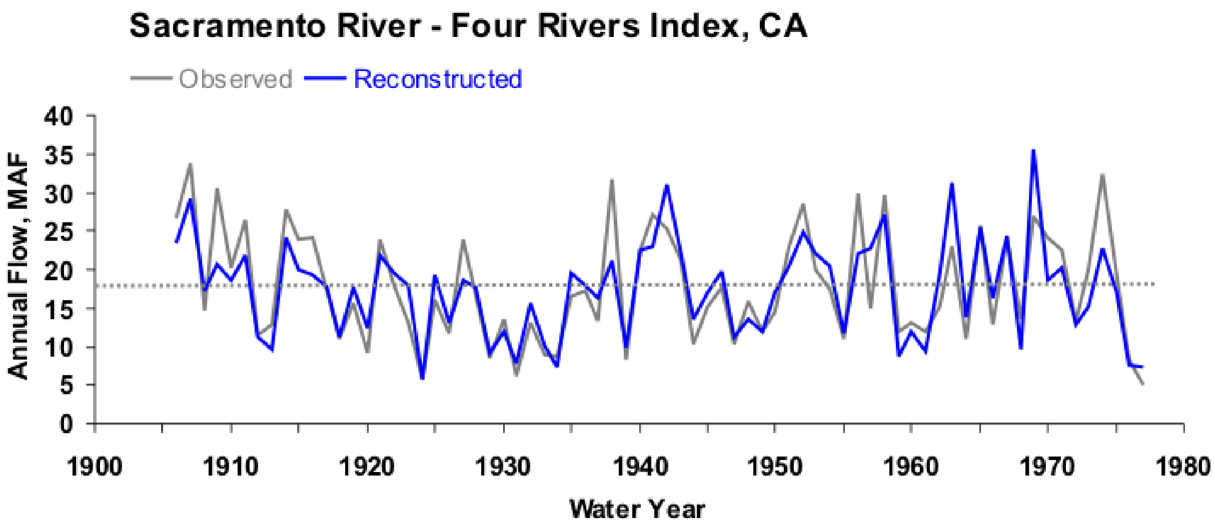
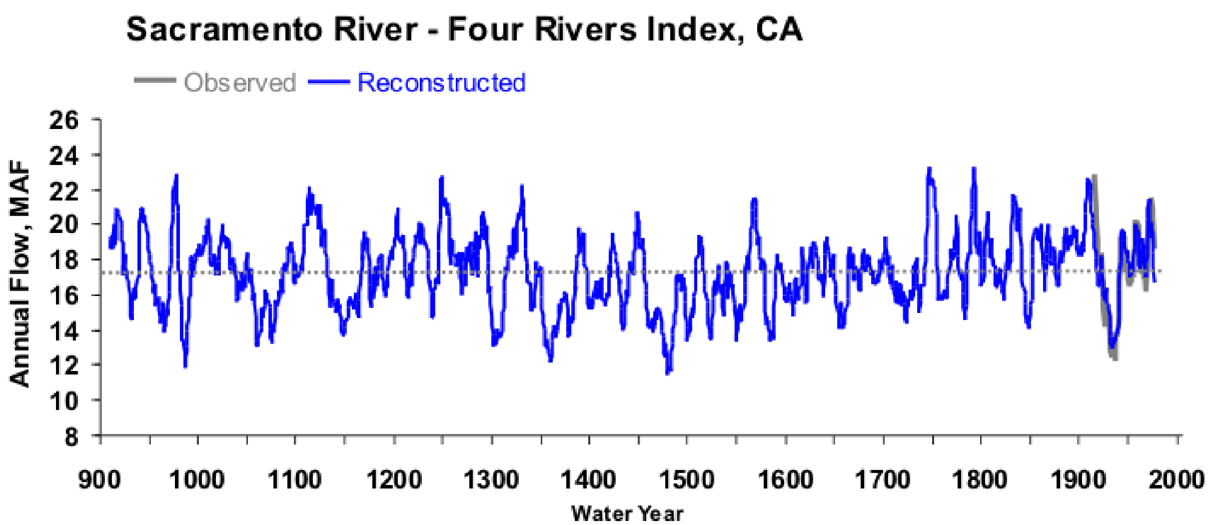
[14] Cook et al., Megadroughts in North America: placing IPCC projections of hydroclimatic change in a long-term palaeoclimate context, Journal of Quaternary Science, DOI: 10.1002/jqs.1303 (2009). Available at http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/PCFFA&IGFR/IFR-2_Cook.pdf

example, mean flow is reconstructed at 73 percent of normal (1906-2008 observed mean, 23.8x106 acre-feet) for the 25-year period ending in 1480.



Observed (black) and reconstructed (blue) annual Sacramento River annual flow, 1906-1977. The observed mean is illustrated by the dashed line.



The 10-year running mean (plotted on final year) of reconstructed Sacramento River flow, 901-1977. Reconstructed values are shown in blue and observed values are shown in gray. The long-term reconstructed mean is shown by the dashed line

3. Shifts in Runoff Due to Climate Change

a.) Regional Bias in CMIP Climate Change Models

In evaluating the climate modeling of shifts in runoff, it is important to understand the bias in the ensemble of 112 climate change model / GHG scenario projections in the Coupled Model Intercomparison Project Third Assessment Report ("CMIP3") database. There is also bias in the newer CMIP5 database. The collection of models is known to have significant problems in reproducing the climate over Western North America.

While the CMIP3 database climate change models was bias-corrected to match historical precipitation in Western North America, bias correction works best when the models are only slightly different from the hydrology they are representing. The larger the bias correction, the more the risk that the bias correction overwhelms any projected shifts in climate.

A 2013 study by the Intergovernmental Panel on Climate Change ("IPCC") included evaluations of how well the CMIP3 database of global climate models represented regional climates. (Gregory Flato et. al., Climate Change 2013 The Physical Science Basis, Chapter 9: Evaluation of Climate Models).[15] This study showed that, while the CMIP3 ensemble does a reasonable job of reproducing historic precipitation over Eastern North America, Europe and the Mediterranean, and East Asia, it's significantly wetter than Western North America. (p. 810-812.)

The graph on the next page (and the closeup below, from the graph) shows just how much wetter the global climate models are than Western North America. Black lines are historical precipitation, estimated by different studies.[16] They are close but not identical.

The turquoise blue line is the mean projection by the CMIP3 set of models, and the shaded blue area shows the range of CMIP3 projections. There is now a new set of models called CMIP5. The CMIP5 mean projection is red and the CMIP5 range of projections are are shown in purple. The regions are denoted with three letter codes. WNA is Western North America. ENA is Eastern North America. CAM is Central America, TSA is Tropical South America, SSA is Southern South America. EUM is Europe and the Mediterranean, NAF, CAF

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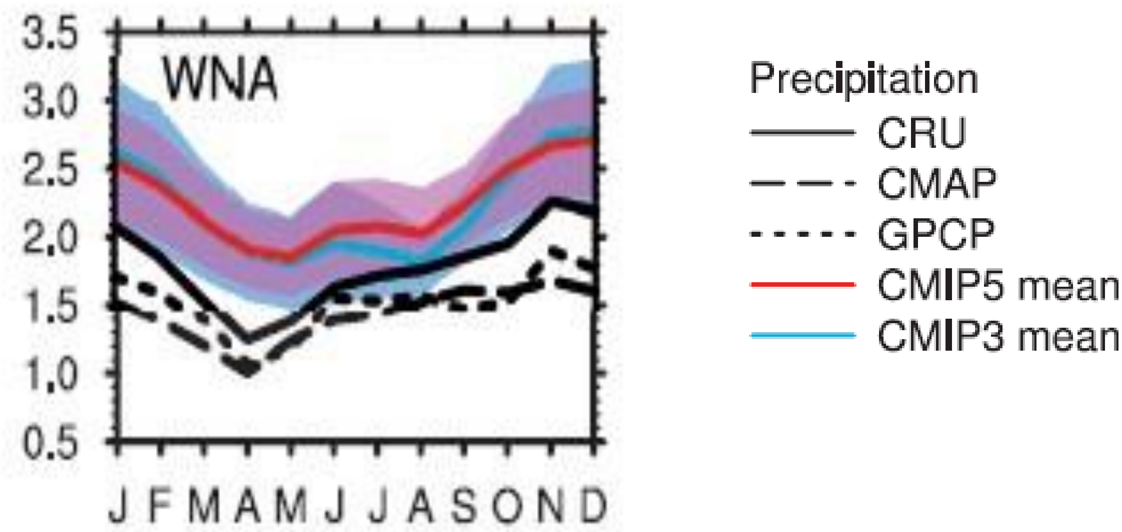
[15] Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason and M. Rummukainen, Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2013. Cambridge University Press, Cambridge, United Kingdom and New York, NY, US. Available at http://www.climatechange2013.org/images/report/WG1AR5_Chapter09_FINAL.pdf

[16] CRU is Climactic Research Unit, CMAP is CPC Merged Analysis for Precipitation, and GPCP is Global Precipitation Climatology project.

and SAF are North, Central, and South Africa. NAS, CAS, EAS, SEA are North, Central East, and Southeast Asia.



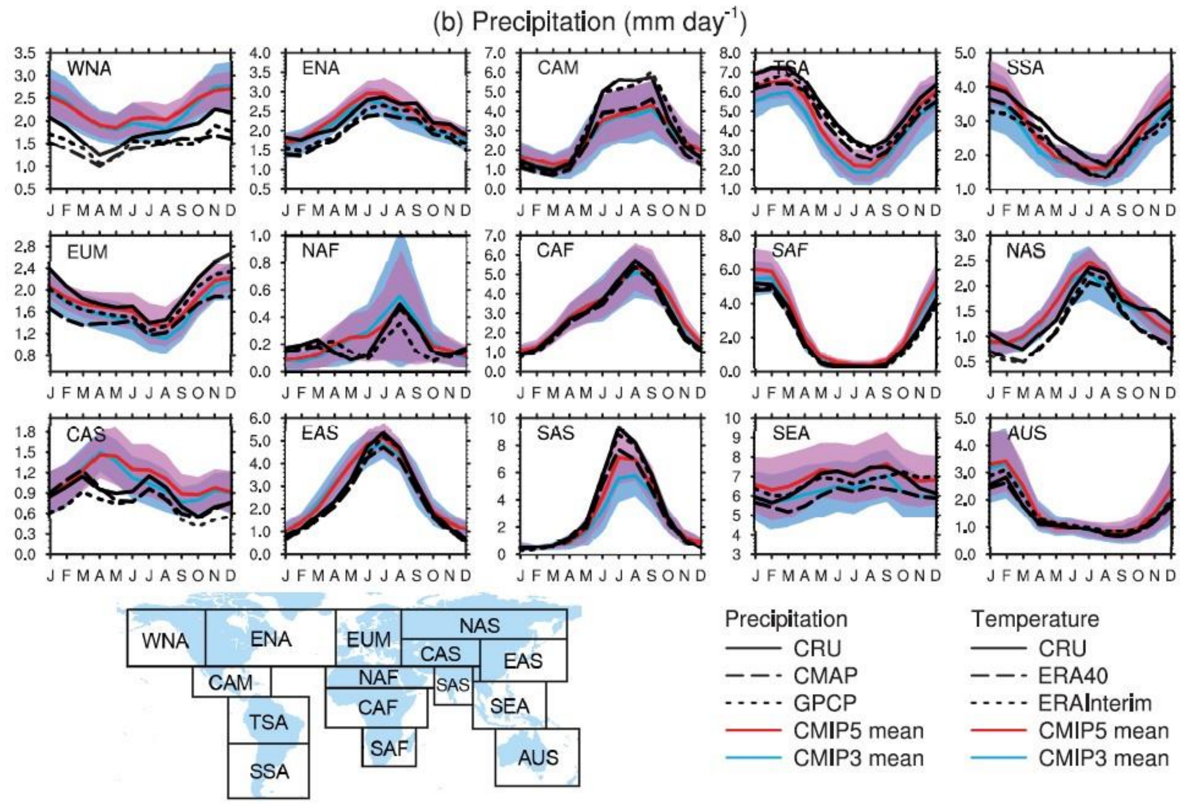
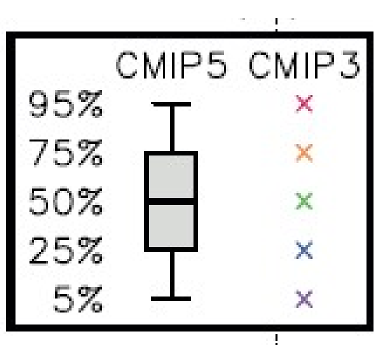
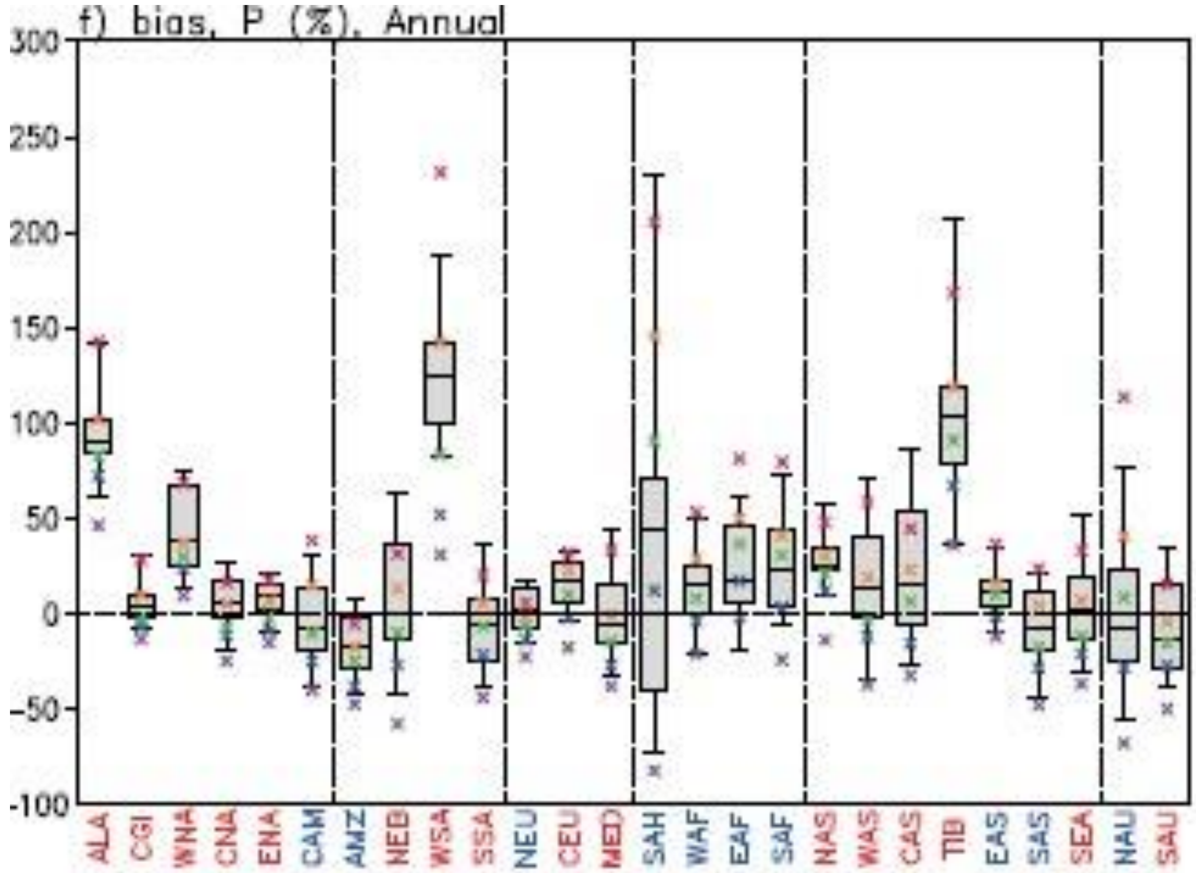


Figure 9.38 | Mean seasonal cycle of (a) temperature (°C) and (b) precipitation (mm day^{-1}). The average is taken over land areas within the indicated regions, and over the period 1980–1999. The red line is the average over 45 CMIP5 models; the blue line is the average over 22 CMIP3 models. The standard deviation of the respective data set is indicated with shading. The different line styles in black refer to observational and reanalysis data: Climatic Research Unit (CRU) TS3.10, ECMWF 40-year reanalysis (ERA40) and ERA-Interim for temperature; CRU TS3.10.1, Global Precipitation Climatology Project (GPCP), and CPC Merged Analysis of Precipitation (CMAP) for precipitation. Note the different axis-ranges for some of the sub-plots. The 15 regions shown are: Western North America (WNA), Eastern North America (ENA), Central America (CAM), Tropical South America (TSA), Southern South America (SSA), Europe and Mediterranean (EUM), North Africa (NAF), Central Africa (CAF), South Africa (SAF), North Asia (NAS), Central Asia (CAS), East Asia (EAS), South Asia (SAS), Southeast Asia (SEA) and Australia (AUS).

Box and whisker plots in the Flato analysis show that for the 50th percentile, the ensemble of 112 CMIP models is approximately 30-40% wetter than historical conditions in Western North America for October through March, and approximately 25% wetter annually.





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Western North America (WNA)

b.) BDCP /WaterFix Approach to Uncertainty in Climate Change Models

Appendix 5A-D of the BDCP Draft EIR/ Draft EIS shows that CH2M Hill originally proposed to deal with uncertainty about regional climate models by developing projections for subsets of the global climate model / climate scenario ensemble. The ensemble was divided into 4 quadrants with projections of more warming and less warming, and drier or wetter. A Central Tendency for the ensemble was also calculated. (Appendix 5A-D, p. 35-36).

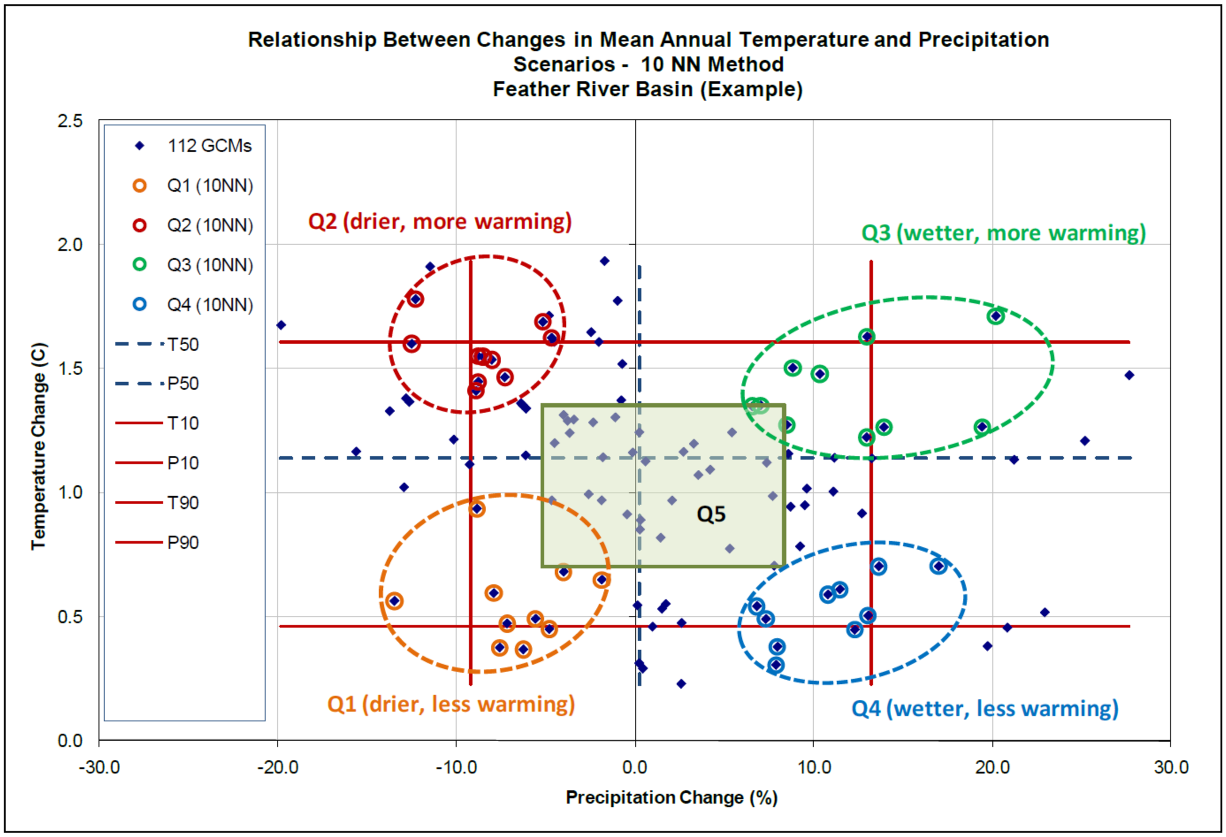


Figure 5.A.2.2-1. Example of Downscaled Climate Projections and Sub-Ensembles Used for Deriving Climate Scenarios (Q1–Q5), Feather River Basin at 2025[1]

Appendix 5A-D, p. 33 stated that "[t]he selected approach for development of climate scenarios for the BDCP incorporates three fundamental elements. First, it relies on sampling of the ensemble of GCM projections rather than one single realization or a handful of individual realizations. *Second, it includes scenarios that both represent the range of projections as well as the central tendency of the projections.*" (emphasis added).

Figure 18. Appendix 5A-D of the BDCP DEIR/DEIS, SWRCB-4 p. 44.

Table 2. Recommended Analytical Tools and Timelines for Consideration of Climate Change Implications

		Uncertainty in Regional Climate Change: Scenarios (Quadrant Approach)					
	SLR (cm)	No Climate Change	Q1	Q2	Q3	Q4	Q5 (central)
Uncertainty in Sea Level Rise	0	NT, ELT, LLT	S	S	S	S	S
	15 (central)	S	ELT	ELT	ELT	ELT	ELT
	30	S					
	45 (central)	S	LLT	LLT	LLT	LLT	LLT
	60	S					
	140	S					
	140 + 5% amplitude increase	S					

NT = Near-Term; ELT = Early Long-Term; LLT = Late Long-Term; S = Sensitivity analysis; FNA = Future No Action

CALSIM II & DSM2 (FNA + Alternatives)

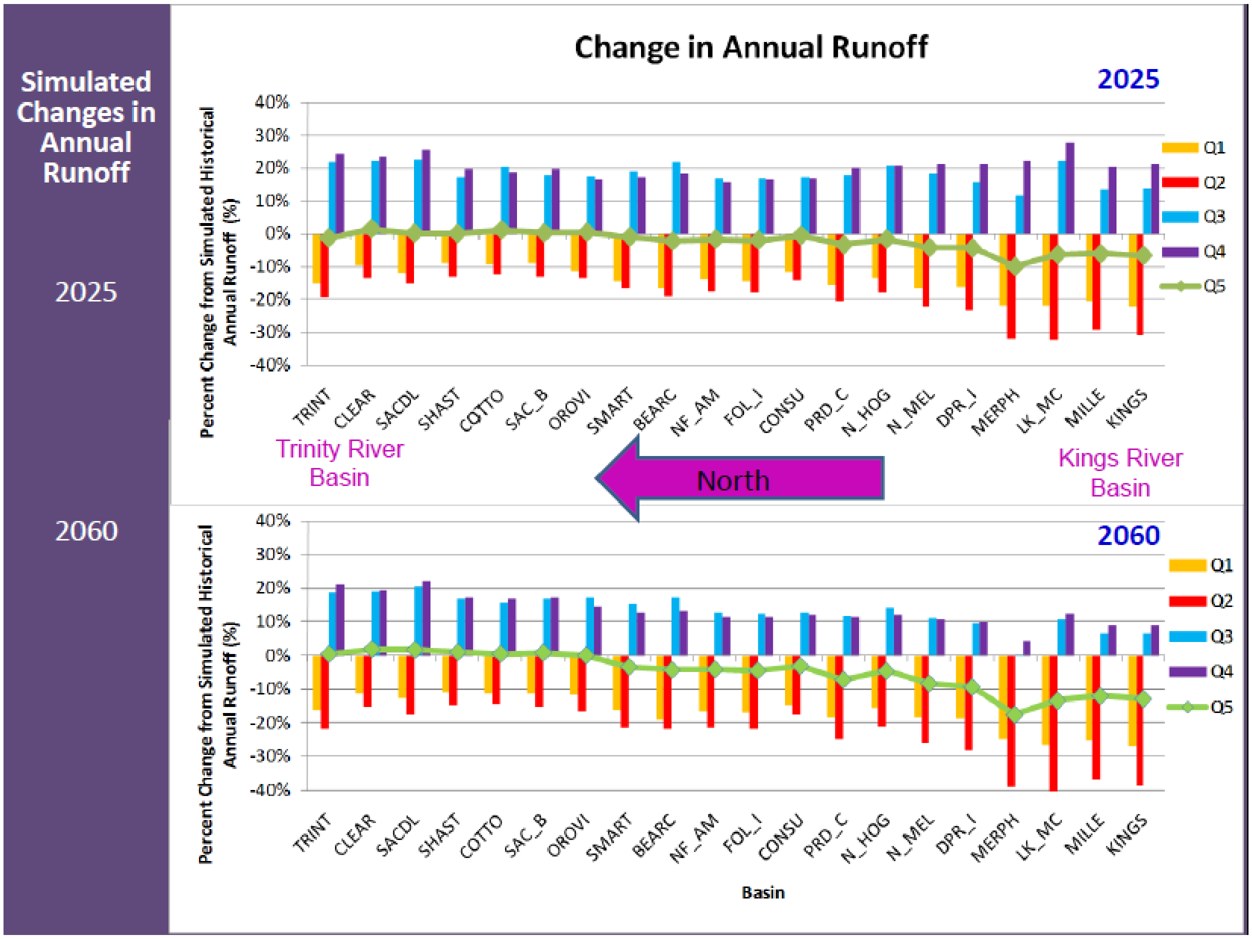
CALSIM only (FNA + Alternatives bracketing analysis)

S Sensitivity Analysis (FNA only)

No modeling

This would have been a reasonable approach to uncertainty about regional climate change scenarios if it was carried through to the final WaterFix modeling. It also would have provided information on possible climate shifts. Instead, only the single "Central Tendency" projection has been used for most BDCP and WaterFix modeling and model results. The Central Tendency scenario provides no information about uncertainty in the BDCP / WaterFix projections of shifts in hydrology.

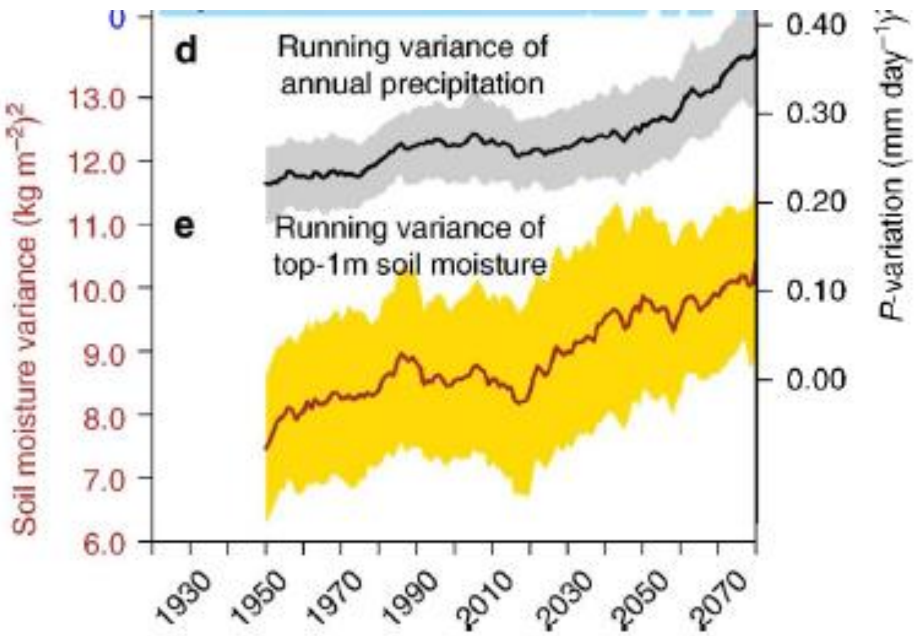
As one can see from the graph on the next page of potential changes in runoff, the differences are large.



4. Change in Frequency of Extreme Events

A recent study by Jin Ho Yoon, S.-Y. Simon Wang, et. al., at the University of Utah using CMIP5 models[17] found that both extremely dry periods and and extreme flooding increase by 50% toward the end of the 21st century. Yoon et. al. defined extreme events as at the 2nd percentile. Such an increase in extremely wet events could increase the frequency of 200 year and 500 year flood events.

[17] Increasing water cycle extremes in California and relation to ENSO cycle under global warming, Nature Communications, 2015. Available at http://www.nature.com/articles/ncomms9657. Accessed on March 31, 2017.



The engineering for the WaterFix tunnels is using current flood stage projections, although there were future projections with climate change produced for the Delta Risk Management Strategy.[18] The analysis also uses Manning's equation to estimate flood stages in the Delta and on the lower Sacramento and San Joaquin rivers due to sea level rise. This is an extremely simplistic approach that was questioned by the peer review panel, even for use in the Delta Risk Management Strategy.

Given recent experiences with both the driest January on record in some locations in 2014, and the wettest January on record in some locations in 2017, the risk of assuming current flood stages for new conveyance should be carefully considered.

[18] Mineart, P., MacDonald, T., Huang, W. Technical memo on Flood Elevations and Protection. Available at http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/petitioners_exhibit/dwr/DWR-661.pdf